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SUMMARY PAGE

THE PROBLEM

Extensive use of the ballistocardiogram (BCG) as a sensitive screening device for heart disease, through assessment of myocardial efficiency, has never materialized. Although many criteria for the diagnosis of heart disease have evolved, considerable overlap between normals and abnormals has limited their usefullness. A greater knowledge of biologic factors influencing the ballistocardiographic wave form might facilitate progress in this area.

FINDINGS

Ballistocardiograms were recorded on a large group of healthy men, 42 to 54 years of age. Various anthropometric, laboratory, and personal history factors were studied to determine how they related to the BCG wave form. Wave amplitudes and durations were influenced by the factors more than has previously been recognized. It appears that, until the factors and their interrelationships are more precisely evaluated, the strictly quantitative use of BCG standards derived from groups to determine such things as stroke volume, among others, must be regarded with caution. The results seem to indicate that serial BCG's will be necessary for complete evaluation of an individual's cardiovascular status.

ACKNOWLEDGMENTS

We are indebted to Mr. Carroll Hixson for his technical advice concerning ballistocardiographic procedures and to Mrs. Margaret Duty and Miss Mary Ann Overman for assistance in processing the data. LTJG Norman E. Lane and LCDR Robert J. Wherry, Jr., contributed to the statistical analysis. Miss Patty Sherman performed the tedious BCG measurements.

INTRODUCTION

In 1940 a psychophysiological study of 1056 young Navy flyers was carried out with successive re-evaluations 12, 17, and 23 years later (1). During the last and the most comprehensive evaluation distributions and intercorrelations were made with a wide variety of physical, clinical, and laboratory determinations, including the ballistocardiogram (BCG), in 649 of the remaining 815 members of the group (2).

The BCG to date has proven to be less useful in the study of clinical patients than desired. Perhaps this has been because of the lack of knowledge of factors which might allow modification of previous empirical clinical judgements regarding the BCG. Therefore, it seemed worthwhile to use our body of information as it became available to relate the wave form of the BCG to a number of selected variables in the hope of presenting previously unavailable useful information to those investigators concerned with the improvement of ballistocardiography.

PROCEDURE

SUBJECTS

Details on the composition of the group, methodology, and tests are available in previous publications (1,2). Data for the present analyses were obtained during the 1963 re-evaluation and are based only on those men aged 42 to 54 who were essentially free from cardiovascular or related diseases. Subjects were excluded from this "healthy" population if they were found to have any of the following disorders: coronary heart disease (definite or probable criteria as defined previously) (1); electrocardiographic abnormality (arrhythmias, bundle branch block, T wave inversion, et cetera); hypertension (blood pressure exceeding 160 mm Hg systolic or 95 mm Hg diastolic, or a previous history of hypertension); history of diabetes or glycosuria; thyroid disease; abnormal vital capacity (less than 3.5 liters); kyphoscoliosis; or chronic debilitating disease or carcinoma. Of the first 350 men examined, 200 were found to meet the criteria imposed and had complete BCG data.

METHODS AND MATERIALS

The ballistocardiograms were obtained in the mid-morning, usually at least two hours after a glucose load of 100 grams had been given orally. The modified Astro-Space Laboratories Air-Bearing Bed, weighing 15.75 pounds, was used (Appendix A, Figure A1). Longitudinal and lateral acceleration tracings were obtained using a Donner 4310 force-balance linear accelerometer with a full scale output of ±15 volts for a ±0.25 g input and a natural frequency of 100 cycles per second. The output of each accelerometer was passed through a low-pass filter with a corner-frequency of 35 cycles per second and a 6-decibel octave rolloff. Tracings were recorded on a modified 4-channel direct writer Sanborn 964 at a paper speed of 50 millimeters per

second. The apparatus was calibrated daily, and standardized regularly with 100 pounds of weight and a 10.5-pound pendulum on the bed. The effect of adding weight is recorded graphically in Figure A2 of Appendix A.

Millimeter amplitudes may be converted to milli-g's as five millimeters equal one milli-g. One milli-g represents 0.001 x 980 centimeters/second^2 or 0.001 x 32.174 feet/second^2.

Simultaneous electrocardiographic lead II and carotid pulse tracing comprised the remainder of each record. A carotid pulse transducer, Infratron model A, with modified Infratron model E control unit, was used.

The subject was strapped into a hamess with his feet firmly against an adjustable foot board. After he was relaxed the bed was then balanced on an air cushion. Tracings were obtained during quiet respiration, held inspiration, and held expiration prior to a final recording in held midexpiration. At least two records were obtained in held midexpiration to reduce the chance of loss of record due to artifact.

The longitudinal ballistocardiographic records were analyzed using tracings recorded in the held midexpiration position. These records were measured by a technician according to a prescribed protocol, and the results were checked for accuracy by one of the investigators. Three consecutive cycles were measured to the nearest one-half millimeter (0.01 second on the time line) in an area with stable baseline. Records were rejected if obvious artifacts or baseline instability was present.

Wave measurements based on the use of the trough of G as a baseline included: amplitudes GF, GH, GI, GJ, GK, GL, and GM; durations* Q-H, Q-I, Q-J, G-H, J-K, H-L, and P-Q (ECG). The R-R interval, DRR, of the simultaneous electrocardiogram was also measured. Other values which were derived from these basic parameters were amplitudes HI, HK, HJ, IJ, and durations Q-K, I-J, H-J, G-Q, H-I, and Q-L (Figure 1).

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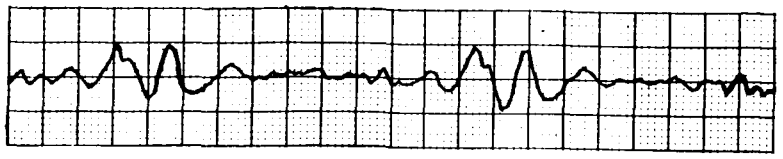
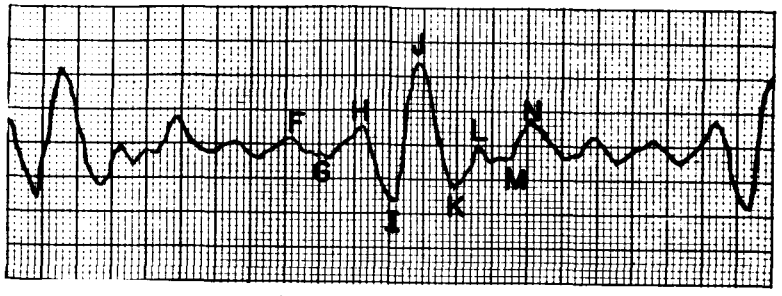
*All durations hereafter will be preceded by a D to distinguish them from amplitude, for example, DGH.



LATERAL



LONGITUDINAL

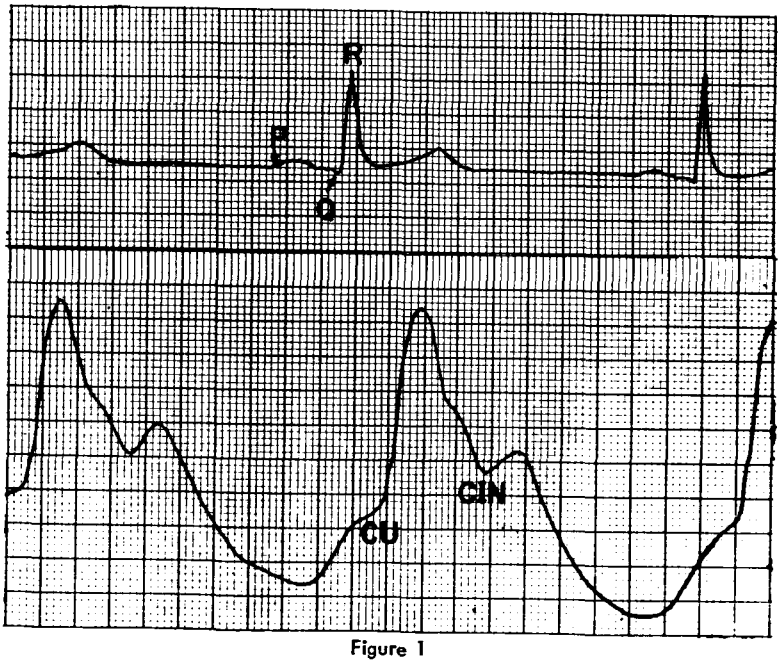


Figure 1

Reproduction of an air bed BCG tracing. Items labeled are believed (ref. 3) to represent positions of the cardiac cycle as noted:

G-H = isometric contraction
H = opening of aortic valve
H-I = rapid left ventricular ejection
K-L = blood hitting peripheral circulatory system
L = closing of aortic valves
L-M = isometric relaxation
M-N = rapid filling wave

(It should be noted that part of the above is disputed by some workers. Onset of isometric contractions may precede H by 0.07 second and onset of left ventricular ejection may precede H by 0.035 second.)

CU = carotid upstroke
CIN = carotid incisuria

Paper speed 50 mm/sec.

Analyses of measured durations and amplitudes were done by Pearson Product-Moment correlations. All the originally measured records were not included in the final analysis because occasionally one item had not been recorded for a particular tracing, resulting in rejection of that particular data card.

Each ballistocardiographic measurement was correlated with the other amplitudes and durations listed above (Appendix A, Table A1) as well as with the 25 variables (2) thought to be of interest:

1. Age
2. Cigarette Amount*
3. Cigarette Years*
4. Systolic Blood Pressure (Supine, Basal)
5. Pulse Pressure (Supine, Basal)
6. Protein Bound Iodine
7. Glucose (2 hr after 100 gm glucose)*
8. Triglyceride (calculated from lipoproteins)
9. Cholesterol
10. Vital Capacity
11. Inspiratory Capacity
12. Expiratory Reserve
13. Transverse Diameter Heart
14. Cardiothoracic Index
15. Maximal ST Depression After Exercise (Max Z aft ex)
16. Height
17. Weight
18. Body Fat
19. Lean Body Mass
20. Endomorphy
21. Mesomorphy
22. Ectomorphy
23. Biacromial Diameter
24. Chest Breadth
25. Chest AP Diameter

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*Coded values (2)

RESULTS

The means, standard deviations, and ranges of the amplitudes and of the durations of the 200 ballistocardiograms studied are listed in Tables I and II, respectively.

Table I

Ballistocardiographic Amplitudes (mm)

Wave	Mean	Standard Deviation	Range
GF	5.5	3.1	0.6 to 16.5
GH	7.6	3.9	0.6 to 24.8
GI	5.0	3.1	15.6 to - 4.0
GJ	13.5	5.5	3.5 to 40.3
GK	3.4	3.0	13.1 to - 9.8
GL	5.3	3.9	-4.5 to 18.5
GM	1.5	2.6	10.6 to - 5.6
HI	12.6	5.1	3.1 to 31.1
HJ	5.9	3.6	-1.1 to 19.8
HK	11.1	5.2	-1.6 to 31.6
IJ	18.5	7.2	6.1 to 48.9

Table II

Ballistocardiographic Durations (mm)

Duration	Mean	Standard Deviation	Range
DQG	-0.5	1.7	-6.3 to 4.3
DQH	4.7	1.1	1.8 to 7.6
DQI	8.0	0.8	6.0 to 11.5
DQJ	12.2	1.4	8.6 to 16.0
DQK	17.8	2.0	10.9 to 24.3
DQL	21.8	2.8	12.3 to 30.1
DPQ	8.3	1.6	4.8 to 12.0
DGH	4.2	1.3	1.0 to 9.1
DHI	3.3	1.0	1.1 to 6.3
DHJ	7.4	1.4	3.1 to 11.3
DHL	17.0	2.8	6.8 to 25.1
DIJ	4.1	1.1	1.6 to 7.4
DJK	5.6	1.6	1.8 to 13.3

A composite ballistocardiogram, illustrated in Figure 2, for these middle-aged healthy men differs slightly from expected in that the amplitude of GH is relatively high. The composite BCG was drawn from averages and standard deviations obtained in this series; it does not include deviation of durations. Of interest is the fact that it would have been considered within normal limits if an adaptaion of Moss' criteria were followed (4).

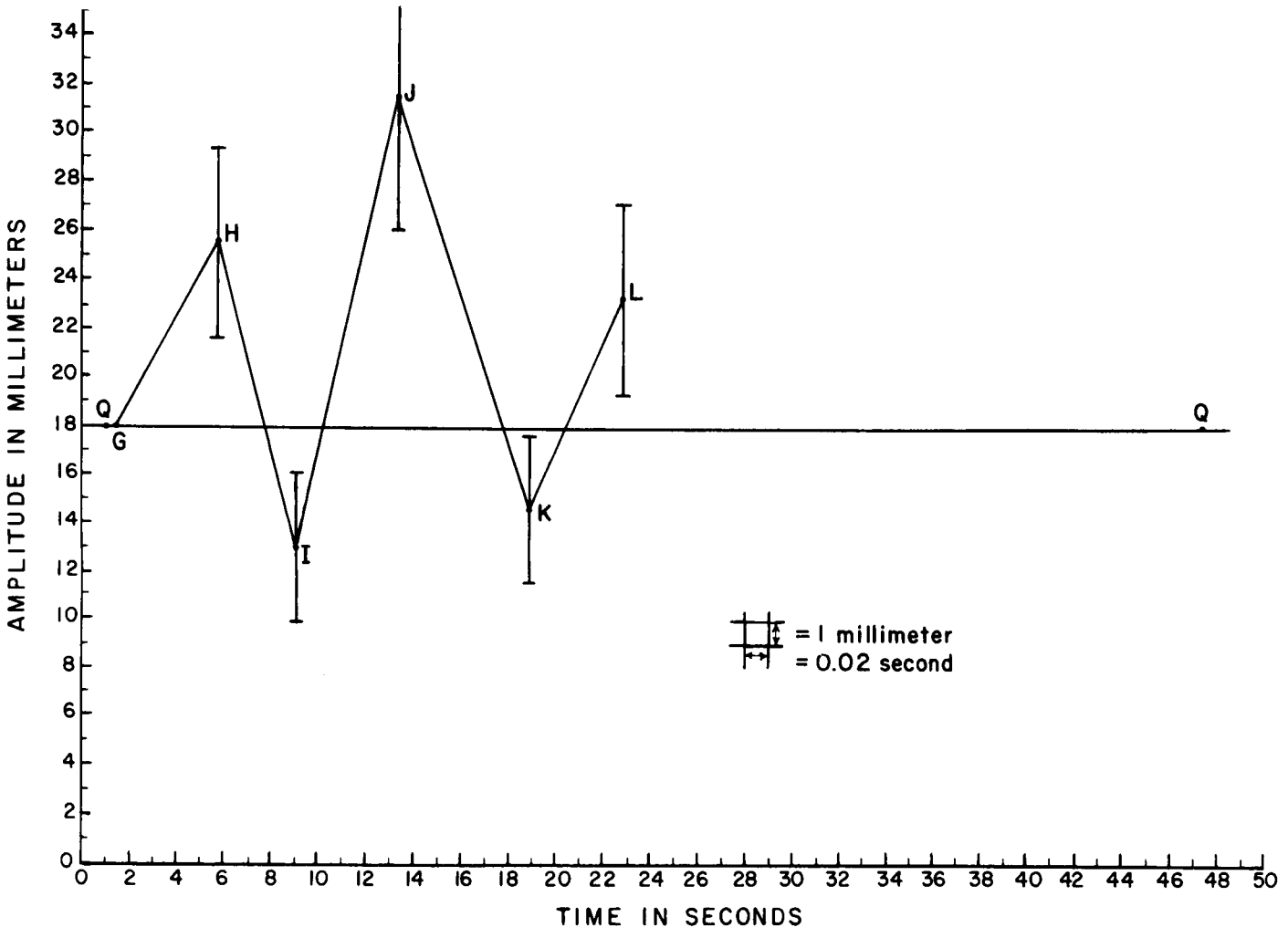

Figure 2

This figure illustrates the composite BCG wave form drawn from mean values in this group. One standard deviation is represented by a point above and below each mean point. Each division of the horizontal axis represents one millimeter which represents 0.02 second.

ZERO ORDER CORRELATIONS

Many parameters of the wave form were highly interrelated (Appendix A, Table AI). The GF complex accounted for more than 50 per cent of the variance in GH, GJ, and GL; GH was similarly related to GJ, HI, and HK; GI to IJ; GJ to HI and IJ; HI to HK; and HJ to IJ. A distrubing factor then is likely to affect a multiplicity of complexes indirectly and cause distortion of several wave form components, for example, GF disruption will change GH, GJ, and GL. Associations of such magnitude were also noted among several of the durations: DQJ to DIJ and DHJ; DGH to DQG; and DHL to DQK and DQL.

The observations on the ballistocardiographic correlates, though not necessarily reflecting cause and effect, were considered significant if the associations exceeded the .05 significance level. Nondirectional significance values for the correlation coefficients at the .05 and .01 level were .138 and .183,respectively. A number of correlations very close to the .05 level would have been significant if the easily justified one-tailed significance values had been used. Further consideration of these borderline associations in the multiple correlations are of some value. It also must be remembered that the homogeneity of the study group will limit the magnitude of the correlations.

PERSONAL HISTORY

Amplitudes (Table III)

Age related best to GL though not significantly; yet it must be remembered that the age range in this group of cohorts varied only from 42 to 54 years, somewhat limiting the strength of any correlations. Interestingly, the amount of cigarettes smoked was associated with a decrease in GK, whereas years of cigarette smoking was positively related to GF. Because of the limited age range there also was no relationship between age and years smoked. It is conceivable that the amount smoked and years smoked produce different pathophysiologic end results, but is more likely that the ballistocardiographic amplitudes are a function of different parameters, or that some of the associations are merely chance.

Table III

Personal History Correlates of the BCG

	Amplitudes										
Variable	GF	GH	GI	GJ	GK	GL	GM	HI	HJ	HK	IJ
Age	046	087	-107	041	031	128	-094	001	-032	085	-016
Cig Amt	029	-046	-107	-093	-142	-002	-109	-100	-090	-116	-117
Cig Years	137	105	-040	009	-027	110	-035	056	-103	067	-011

Durations (Table IV)

Age related to an increase of DQI and DQJ. In contrast, cigarette amount was associated with shortened DQL, DHI, and DHL, and cigarette years was associated with a shortened DHL, reaching significance only with the cigarette amount–DHL relationship.

Table IV

Personal History Correlates of the BCG

	Durations												
Variable	DQG	DQH	DQI	DQJ	DQK	DQL	DPQ	DGH	DHI	DHJ	DHL	DIJ	DJK
Age	008	051	165	141	069	117	-036	051	086	103	096	053	-046
Cig Amt	-001	089	-050	-045	-063	-132	-083	068	-131	-112	-163	-018	-039
Cig Years	-010	096	030	-003	-087	-099	030	065	-073	-075	-133	-028	-108

PHYSICAL EXAM

Amplitudes (Table V)

Of the variables investigated, the heart rate showed the most numerous and significant individual correlations with the BCG. Unexpectedly, the various parameters of blood pressure did not show more meaningful relationships, but the range of blood pressure was restricted by excluding individuals with hypertension. The mean blood pressure for this population was 123 mm Hg systolic and 78 mm Hg diastolic, with standard deviations of 10.0 and 7.2, respectively.

Diastolic blood pressure and arcus senilis showed no significant relationships and systolic blood pressure none; therefore the former two are not shown in Tables V and VI. An increased heart rate related to diminished GI, GK, and GM complexes but to a larger GF amplitude. From the general trend it appeared as though increased heart rate tends to increase the amplitude of positive deflections and decrease negative deflections. Pulse pressure was associated with an increase in HJ amplitude.

Table V

Physical Exam Correlates of the BCG

Amplitudes

Variable	GF	GH	GI	GJ	GK	GL	GM	HI	HJ	HK	IJ
DRR	-220	-123	334	-035	193	-122	197	111	081	018	121
Syst BP Sup Bas	028	013	040	063	115	024	103	035	080	077	065
Pulse Press Sup	021	001	106	096	100	-001	114	066	144	059	120

Durations (Table VI)

A number of durations, DQL, DPQ (ECG), DHI, DHJ, and DHL showed an inverse relationship with heart rate; DQG and DQH were positively related to rate. (Note that mean DQG, Table II, is a negative number.) Pulse pressure was associated with a decrease in DHI, but systolic blood pressure demonstrated no significant relationships.

Table VI

Physical Exam Correlations of the BCG

Durations

Variable	DQG	DQH	DQI	DQJ	DQK	DQL	DPQ	DGH	DHI	DHJ	DHL	DIJ	DJK
DRR	202	-223	017	039	105	193	281	071	242	208	277	041	094
Syst BP Sup Bas	-027	-008	120	-022	007	009	006	-039	-088	-018	009	063	029
Pulse Press Sup	-021	074	-113	-007	-033	-015	-110	035	-166	-064	-047	077	-034

LABORATORY

Amplitudes (Table VII)

No relationships were noted with the PBI, but blood glucose values after a 100-gm carbohydrate load were negatively related to the GI amplitude. Triglyceride was associated with an increase in GL. Values for GJ and IJ were diminished as serum cholesterol increased. Vital capacity had significant relationships in a positive direction with GK, and HK had a borderline relationship. Heart size as represented by the transverse diameter and cardiothoracic index showed no relationsips. Nonjunctional ST depression was associated with an increase of GI.

Durations (Table VIII)

DQH decreased with higher values of the two-hour glucose; DQG shortened, but DGH lengthened with an increase of triglycerides; cholesterol had no significant effect on the durations. Pulmonary functions demonstrated a number of relationships of high magnitude with the durations: Vital capacity varied directly with the duration of DQH, DQI, DQJ, DQK, DQL, DHL, DIJ, and DJK; inspiratory capacity with DQI, DQJ, DQK, DQL, DPQ, DHL, and DJK; expiratory reserve with DQG, DQH, and DQJ. The durations DQL, DPQ, and DHL lengthened with an increase in the transverse diameter of the heart; maximum nonjunctional ST depression postexercise was associated with a decrease in DQJ and DHJ.

ANTHROPOMETRY

Amplitudes (Table IX)

Many borderline associations, especially with GM and HJ were not statistically significant but did seem consistent and meaningful. Taller men had lower amplitude of GM and HJ while heavier individuals demonstrated smaller HJ and IJ complexes. Body fat, lean body mass, and endomorphy were related inversely to HJ, but only endomorphy reached significance. Endomorphs also tended to have less GI, GM, and IJ amplitudes; mesomorphs had greater depth of GK and GM, while ectomorphs had a less pronounced GK complex. The only significant relationship among the diameters was the greater depth of GK with increased chest breadth.

Table VII

Laboratory Correlates of the BCG

	Amplitudes										
Variable	GF	GH	GI	GJ	GK	GL	GM	HI	HJ	HK	IJ
PBI	071	060	-086	026	-084	114	-087	-007	-026	-004	-018
Glucose 2 hr pp	-007	022	-138	-068	040	017	023	-068	-126	040	-113
Cal Trigly	102	121	-082	033	-002	169	-038	042	-084	092	-012
Cholesterol	-110	-090	-081	-157	-083	-013	-084	-118	-137	-116	-153
Vital Capacity	079	076	030	086	138	096	015	076	047	137	078
Inspir Capacity	041	044	-034	-030	076	015	048	012	-092	077	-038
Expir Reserve	042	026	033	104	078	097	-007	039	130	064	093
Trans Diam Ht	-067	-036	034	-109	121	-042	061	-007	-124	044	-067
Cardiothor Indx	-087	-063	035	-094	068	-058	064	-027	-071	-008	-055
Max ST Aft Ex*	-018	002	141	074	-017	-066	051	088	110	-009	118

*Max ST Aft Ex represents maximum nonjunction ST depression after exercise.

Table VIII

Laboratory Correlates of the BCG

	Durations												
Variable	DQG	DQH	DQI	DQJ	DQK	DQL	DPQ	DGH	DHI	DHJ	DHL	DIJ	DJK
PBI	092	-057	-079	040	044	091	-033	071	-012	082	109	116	019
Glucose 2 hr pp	064	-151	-047	-040	-095	-108	086	-037	110	071	-051	-012	-082
Cal Trigly	194	-106	-061	-041	026	049	025	165	056	038	089	-009	068
Cholesterol	118	-051	049	-016	010	041	058	109	089	021	061	-060	028
Vital Capacity	-125	159	213	241	302	218	078	-034	018	127	155	146	155
Inspir Capacity	-028	020	155	138	218	185	163	-019	105	125	175	062	145
Expir Res	-167	194	120	151	132	071	-037	-060	-093	008	-003	098	026
Trans Diam Ht	105	-073	025	067	111	138	152	070	093	123	163	077	075
Cardiothor Indx	112	-079	-084	-006	031	096	030	076	011	053	124	062	043
Max ST Aft Ex	-009	-001	-124	-158	-084	-074	-124	-014	-101	-157	-074	-109	041

Table IX

Anthropometric Correlates of the BCG

	Amplitudes										
Variable	GF	GH	GI	GJ	GK	GL	GM	HI	HJ	HK	IJ
Height Standing	081	021	-123	-069	-060	101	-130	-059	-125	-020	-106
Weight	050	014	-108	-127	070	047	-058	-056	-205	051	-143
Body Fat	095	110	-004	-004	021	053	-060	082	-128	097	-006
Lean Body Mass	067	029	-057	-070	089	080	-079	-013	-135	073	-078
Endomorphy	025	043	-144	-094	-070	004	-134	-055	-188	-007	-134
Mesomorphy	-050	-046	053	-087	151	-047	135	-002	-081	052	-042
Ectomorphy	057	039	-055	091	-171	082	-091	-004	094	-069	044
Biacromial Diam	015	014	-001	-065	084	-012	049	010	-112	059	-049
Chest Breadth	075	045	012	-054	148	051	010	042	-132	121	-036
Chest A-P Diam	114	034	-084	-008	128	104	-062	-026	-051	102	-044

Durations (Table X)

Numerous striking associations with all anthropometric variables were apparent, though to a lesser degree with somatotype. Height, weight, body fat, and lean body mass were positively correlated with DQI, DQJ, DQK, DQL, DHJ, and DHL, with the exceptions of body fat to DQK and height to DHJ. DQG, DQH, and DJK were related to height and lean body mass; DHI related to weight; DPQ (ECG) and DIJ to lean body mass; and DHI also related directly to body fat. Mesomorphs demonstrated a longer DPQ (ECG) and DHI, whereas ectomorphs showed a decrease in DGH, DHI, and DHJ but an increase in DQG, DQH, and DJK. Greater biacromial, chest breadth, and anterior-posterior chest diameters correlated with longer DQI, DQJ, and DQK.

Chest breadth and A-P diameter together related to DQL, DHJ, and DHL, but only breadth to DHI and DJK, and A-P diameter to DIJ.

MULTIPLE CORRELATIONS

In order to predict how much of the ballistocardiographic variance could be attributed to the variables investigated, a multiple regression analysis was completed using the Wherry-Doolittle method (5).

The Wherry-Doolittle is an iterative technique which adds one predictor variable to the regression equation on each iteration, recomputes the multiple correlation, and tests the significance of the criterion variance added by the new predictor. The variable selected on each iteration is the predictor which explains the greatest amount of criterion variance independent of the variables already selected. The iterations continue until the F ratio for the significance of the criterion variance added by the selected variable is less than or equal to 1.00.

In the 24 regression analyses, each of the 24 ballistocardiographic parameters was employed as a criterion. For five amplitudes (GI, GK, HI, HJ, IJ) and ten durations (DQG, DQH, DQI, DQJ, DQK, DQL, DHI, DHJ, DHL, DJK) of the ballistocardiogram more than 15 per cent of the variance could be attributed to the 25 variables used as predictors for each analysis. The cumulative multiple R's and Z scores weights for each of these criteria are given in Appendix B.

Amplitude

Multiple correlations for all criteria ranged from .523 with GI as the criterion to .337 for GM.

The most prevalent predictors for those variables in which greater than 15 per cent of the variance is explained were, in descending order of frequency and rank: heart rate, weight, endomorphy, body fat, blood glucose, pulse pressure, and chest

Table X

Anthropometric Correlates of the BCG

	Durations												
Variable	DQG	DQH	DQI	DQJ	DQK	DQL	DPQ	DGH	DHI	DHJ	DHL	DIJ	DJK
Height Standing	-256	247	246	236	389	283	122	-130	-050	056	188	120	266
Weight	-073	074	303	262	260	249	231	-035	171	208	219	112	082
Body Fat	034	-039	176	174	091	140	135	009	184	205	154	098	-047
Lean Body Mass	-144	158	336	310	372	274	215	-062	114	197	212	150	177
Endomorphy	053	-031	112	097	051	091	086	042	127	125	103	044	-027
Mesomorphy	079	-084	114	058	001	-005	194	036	171	117	027	-010	-053
Ectomorphy	-215	167	-082	-035	108	044	-125	-141	-233	-156	-019	015	167
Biacromial Diam	-106	106	251	199	218	137	158	-054	099	123	096	069	090
Chest Breadth	-030	-042	245	140	237	184	224	-075	240	173	198	-001	165
Chest A-P Diam	007	045	204	254	160	180	075	048	118	223	161	177	-037

breadth. Other critical variables included cholesterol, the best predictor of HI and IJ; vital capacity, fourth ranking for GJ; and cigarette years and amount, fourth and fifth ranking for HI.

Duration

With the exception of two multiple correlations DGH (R= .317) and DIJ (R= .361), all of the durations had more than 15 per cent variance explained. With DIJ the most prevalent factors were, in descending order of frequency and rank: heart rate, age, protein bound iodine, blood glucose, and height. Height appeared as the best predictor of five criteria (DQK, DJK, DQL, DQG, DQH) and second best for DHL; lean body mass was the best predictor of DQJ and DQI while weight was the best for DHJ. Other important variables were serum lipids, heart size, chest diameters, pulmonary functions (V.C. and I.C.), systolic blood pressure, and pulse pressure.

DISCUSSION

Regarding the BCG, Rorvik (6) wrote, "Variability is considerable, transition is gradual, and sharp borders are difficult to define." There is considerable overlap between healthy and diseased subjects, and little is known about extracirculatory factors which influence the BCG wave forms. To our knowledge there have been very few attempts (7,8) to relate a number of biologic variables (body fat, weight, height, PBI, blood glucose, et cetera) to BCG amplitudes, durations, or interpretations in either healthy or abnormal subjects in a systematic fashion. Starr (9) stated that an ultra-low frequency record with a light enough table essentially is not altered by the peculiar anthropometry of the subject, but what factors do account for the variation in tracings, other than the mechanical events of circulation? Several authors have mentioned weight in discussing BCG systems (10-12). Foley (13) compared variations in patterns, especially amplitude, between healthy, stocky men and their slender counterparts. Much of the variation in the force BCG tracing has been related to myocardial strength (12).

If there is a relationship between skeletal and cardiac muscle strength, as has recently been postulated (14), would amplitude and duration of the BCG indirectly relate to muscle strength as determined by a dynamometer? It seemed unlikely; yet the information was available and was evaluated. (In this case there was no relationship and coefficients are not presented here.) A more precise knowledge of any confounding factors would enable a better interpretation of the individual record and ultimately enhance diagnosis and clinical estimation of future events.

No attempt has been made to further categorize either the population or the variables studied, but rather to quantitatively assess their association insofar as possible.

Age

Age has long been known as a determinant of the BCG wave form. A decreasing amplitude of GI, HI, HJ, and IJ with increasing age has been reported (4,14). It was not surprising, however, to find a lack of correlation of age with these amplitudes with our limited, group-age range; this finding was verified by multiple correlations in which the only amplitude including age as a predictor was GI (Appendix B).

The positive relationship between increasing age and length of the period from onset of Q to I seems to indicate a decrease in the rate of completion of rapid ventricular ejection (15). Increasing duration of Q to J peak with age points to a lengthening of the time of ventricular ejection in general, which may be taken to represent a decrease in myocardial force of ejection or myocardial ejection efficiency with advancing age. It is interesting that lean body mass and age account for more than half of the explained variance for DQI and DQJ (Appendix B) since Scarborough et al. (7) found no age relation with DQI and DQJ.

Smoking

It has been established that the BCG is altered by smoking only one cigarette in older age groups and in those with coronary heart disease (16). Davis et al. mentioned that GH is accentuated after smoking by patients with coronary heart disease (16). Caccese and Schrager (17) noted "great changes" and "minor changes" in both normals and in those with Buerger's disease or coronary heart disease. Their illustrations show also a decrease in all amplitudes except GH (which increased) in a healthy male, and similar results were shown in one with Buerger's disease. However, there are apparently no previous reports on the possible effect of smoking habit on the BCG form.

Our study shows that cigarette smoking as measured by amount smoked per day (CA) and years smoked (CY) correlated .289 and .256, respectively, with heart rate (DRR). Through influence on heart rate alone, therefore, smoking may modify wave form. Only GK and DHL related to the amount smoked, though there were several borderline associations with either amount or years smoked. Mechanical systole as represented by DHL involves a shorter time period which may be explained by the expected shortening of ventricular systole with increased sympathetic stimulation.

Independently of heart rate, CY contributed to several of the 15 multiple correlations considered, including HJ, DHJ, and DJK (Appendix B); both CA and CY were of importance to the HI amplitude (Appendix B) which represents rapid left ventricular ejection (3). It is notable that cigarette years influenced the BCG more than cigarette amount. Cigarette years contributed positively to HI while cigarette amount contributed negatively. IJ was shown by one-tail significance (-0.119) value to decrease with increasing numbers of cigarettes per day, perhaps indicating a short-term effect or a more rapid build-up of nicotine effect on the heart and/or vasculature. Obviously, smoking

may affect the cardiovascular functions in both acute and chronic fashion as indicated by the BCG.

PHYSICAL EXAM

Blood Pressure and Pulse Pressure

Blood pressure would be expected to influence the various waves of the BCG insofar as it related to vascular diameter, heart rate, heart size, and cardiac ejection of blood. The effect of increasing or decreasing blood pressure in the cardiac ejection of blood has been studied by Starr indirectly (12) and by others (18).

As systolic, basal supine blood pressure increased, the period extending to the end of rapid ventricular ejection (DQI) approached a significant reduction. This relationship is confirmed by the selection of systolic blood pressure as a predictor for DQI after lean body mass and age. In this group the sympathetic nervous system possibly manifested its activity both by increasing blood pressure and the rate of systolic ejection (14). Obviously, only rapid ejection was affected rather than DQL, the entire period of systole.

Pulse pressure has been reported to be influential in determining the configuration of the I wave by Morse (19); however, no correlation was found here with either GI or HI. Pulse pressure was a low order predictor for both criteria (Appendix B), which is in agreement with Mihoczy who, at the First World Congress on Ballistocardiography and Cardiovascular Dynamics, stated that results obtained from model studies do not always correspond to human hemodynamics (20). Of interest is the positive correlation of the pulse pressure with the amplitudes which are related to ventricular ejection, HJ and IJ. Since the pulse pressure contributes to these parameters known to be related to systolic stroke volume and force of cardiac contraction (21), serial ballistocardiographic recordings and pulse pressures might be useful indices for change in stroke volume and deterioration in myocardial force. The fact that HJ and IJ decreased as pulse pressure dropped tends to support this argument since it is known that in myocardial failure these variables do decrease. As pulse pressure increased, time for rapid ventricular ejection decreased also, which is not unexpected in view of the relationships noted above, probably indicating stronger force of myocardial ejection, within the normal range.

Heart Rate

Heart rate apparently is one of the most important determinants of ballistocardiographic wave form in a healthy group. The specific relationships have been given previously. Scarborough et al. noted that at least four factors appeared to influence the duration of the I and J waves: pulse rate, body size, age, and sex (7). They also reported that duration of Q-K (DQK) was negatively correlated with pulse rate in men. Our findings reveal a number of assertive ballistocardiographic correlations with heart rate, the best over-all predictor of amplitude and duration; yet, DQK and DIJ were not among them. There seems to be no acceptable explanation.

LABORATORY FINDINGS

Thyroid Function

In this study the protein bound iodine (PBI) was used as a measure of thyroid status to explore to some degree the relationship of thyroid function to the BCG wave form. PBI level contributed independently of heart rate to DQL, DQG, DQH, and DHL, as indicated by multiple correlations (Appendix B), but otherwise did not relate to the BCG.

In hyperthyroidism increased ballistocardiographic deflections are noted while the reverse is said to be true of hypothyroidism. Our results indicate that the PBI within the normal range apparently has such a small effect on wave form as to be safely ignored.

Glucose Metabolism

It was interesting to note that with higher two-hour post-prandial blood sugar, the amplitude of GI decreased and HJ approached significance in the same direction. Both of these changes, which have been related to the presence of coronary heart disease (22), were corroborated by the multiple correlations.

It is known that an abnormal glucose tolerance represents a late stage in the natural history of diabetes (23). We might wonder whether, as a result of the vascular complications of diabetes (24), BCG alterations as represented by decreased amplitudes and increased time duration for the ventricular systolic waves, might be evident before overt clinical manifestations.

Lipids and Lipoproteins

In the limited age range of our study group there was no age correlation with triglycerides or cholesterol; related BCG differences were not a function of age but of the lipid fractions which were highly correlated positively with each other. The risk of high levels of serum lipids and coronary heart disease is well known (25); it is conceivable that the low GJ, IJ, and HJ amplitudes (borderline significance) were all related to the increased cholesterol level as manifestations of coronary heart disease. These findings are further corroborated by the selection of cholesterol as the best predictor of IJ and second best of HJ. Though cholesterol was not selected for GJ, it also was the best predictor for HI. The increase in amplitude of GL was perhaps the result of increasing rigidity in vasculature due to higher triglyceride levels, but if so, why do cholesterol and glucose not have a similar relationship? Despite the complexities of lipid and carbohydrate metabolism it must be remembered that, by the sheer magnitude of numbers, there may be spurious correlations. These variations if valid are undoubtedly due to long-term effects rather than changes secondary to transient elevation of blood lipids (26). We did not find that cholesterol level and ballistocardiographic wave form were unrelated, as has been reported (26).

A previous study (27) of individuals in the 40 - 79-year age group revealed serum lipids and/or protein abnormalities were higher in healthy subjects with abnormal ballistocardiograms than in those with normal records. However, age dependence of both variables could not be excluded, and only a tentative conclusion that abnormalities of the ballistocardiogram relate to serum protein and lipoprotein could be made. Engelberg (8) found a "suggestive relationship" between the degree of ballistocardiographic abnormality and elevation of serum lipids, especially in those under age 50, but statistical significance was not reported and could not be determined. Since elevated lipid levels were positively related to an enhanced risk of developing coronary heart disease, these alterations of GJ, HJ, and IJ which we have noted may be additional harbingers of clinical coronary heart disease.

Pulmonary Function Studies

GK and HK were the only amplitudes related to pulmonary function, and these varied only with increasing levels of vital capacity; GK became more negative and HK increased in amplitude. Vital capacity, and inspiratory capacity to a lesser extent, seemed to have a significant positive correlation with the duration of all ventricular systolic segments, i.e., longer systolic ejection period. This relationship is not so apparent in the multiple correlations, and may be an indirect association.

Though respiratory maneuvers certainly alter the ballistocardiogram, it was not anticipated that there would be a strong relationship in this healthy group since grossly abnormal results in respiratory function studies led to removal of that individual from our group, and since the contribution of the right heart, which ordinarily is affected by lung disease, to the BCG wave form is thought to be much less than that from the left side (9). Why time from onset of the electrical systole to the onset of mechanical ejection was prolonged is not immediately evident unless it is related to increased vagal tone associated in some way with increased vital capacity.

X-ray and Exercise Electrocardiogram

The relationships between heart size represented by transverse diameter and cardiothoracic index and myocardial strength as reflected by the amplitude of the acceleration curve were not remarkable. Cardiothoracic index ranked low as a predictor for several BCG durations; transverse heart diameter correlated directly with duration of ventricular systole, DQL. There was a strong association with decreased heart rate, and this may be responsible for the relationship. Maximum nonjunctional ST depression after exercise related directly only to GI amplitude, but was associated with shortened DQJ and DHJ.

ANTHROPOMETRY

Height

Height of the individual who is placed on the BCG bed should affect the technique of recording since the patient must be maneuvered to a position such that the bed floats

on air without any other contact (i.e., center of gravity must be directly above the air support). Once this is accomplished, what is the effect of variation in height? Height was the best predictor of DQK, DJK, DQG, DQH, and DQL. We found in our age range no height relationship with I, J, or K amplitudes. Recent studies (19,28) have shown that vasculature has great effect on the wave form. It would seem that differences in the length of the vascular system, as measured indirectly by height, would bring about differences in the deflections. In fact, a significant relationship between height and duration of the systolic complexes has been described (7). Scarborough's suggestion that this is dependent on the length of the aorta seems reasonable since duration of QK is reported to be dependent on time from onset of cardiac excitation to impingement of blood flow on the bifurcation of the aorta.

Weight

The influence of weight was not unexpected in view of the fact that acceleration is related to force and mass (7). HJ and IJ were significantly negatively correlated with weight.

As noted previously, the changing ballistocardiographic standardization deflection as a function of weight using our apparatus is shown in Appendix A, Figure A2. Obviously, the subject's weight should be known for BCG interpretations. Prolonged duration of mechanical systole in the BCG may reflect to a large extent the difficulty in overcoming the inertia of an increasingly large mass. Several items inversely correlated to weight were those which have previously been similarly associated with cardiovascular aging, specifically, amplitudes HJ and IJ (4). Perhaps these relationships are not entirely inertial, but are related to early cardiovascular aging, higher body weight being associated with decreased myocardial strength. Scarborough et al. found no correlation of weight in man with I, J, or K amplitudes (7). However, our group differs from theirs in that the age range was not the same, and the people involved in their study were not aviators or former aviators.

Body size is related to body fat and lean body mass as components of weight, and more meaningful relationships might be expected from these parameters. Body fat and lean body mass were both significantly positively correlated to DQI, DQJ, DQL, DHI, and DHL.

Body fat and lean body mass would readily contribute to the wave form since the body would be assumed, no matter how tightly bound to the bed, to move in relation to the bed, varying somewhat with the amount of adipose tissue between the heart and bed (28). That both of these correlated in the same direction with the above durations may at first glance seem remarkable since they would appear to be divergent factors. It may be possible to explain these relations, however, on the basis that as body fat increases, so generally does weight and as weight increases, so do these durations. People with larger lean body mass may be in better physical "shape" with greater vagal tone and resultant prolongation of systolic durations. However, since weight, body fat,

and lean body mass were all highly correlated with each other (all greater than .399), it seems more likely that weight is the primary factor involved here.

Body fat and lean body mass approached a significant inverse relationship with only one amplitude, HJ. The definite correlation of HJ with weight and endomorphy, similar factors, all in the same direction, indicates the possible relationship of these variables to some factor intrinsic to all.

Somatotype, by virtue of weight, distribution of fat, and variation in center of gravity, would likewise be expected to have an effect on wave form and duration of portions of the BCG. It has been noted that presence or absence of limbs will influence a tracing such that, in those without legs, amplitudes will be larger (29). Many factors peculiar to a given somatotype might be reflected in the hemodynamics of cardiac ejection. Ectomorphs demonstrated the most significant associations, frequently opposite to mesomorphs in items mutually influenced. While these relationships are of interest, an explanation of the relationships is probably not possible in view of the multiplicity of factors involved. It does seem strange that there were so few opposite effects when comparing endomorphic subjects with ectomorphic ones.

Diameters of the upper thorax related to amplitudes and durations also were thought to offer unique information because of the partial dependence of the configuration of the heart and major vessels on the anatomical structure of the chest cavity. Chest breadth was related to duration of ventricular systole in such a fashion that systolic durations increased as the chest widened, and the same was true of increasing A-P diameter. Biacromial diameter was similarly related to systolic durations. Other than GK, the importance of the diameters is reflected in the numerous correlations with duration rather than amplitudes. Their predictive capabilities are manifest in the H and J waves, namely, HJ, DQJ, DHJ, and DHI.

The availability of a large number of variables made it possible to delineate those human factors which contribute to ballistocardiographic acceleration wave formation. Attempts were made to explain some of these relationships on a physiologic basis, not to prove cause and effect, but only to emphasize areas where this information seemed to suggest the necessity of more extensive evaluation. It appeared that relationships of BCG wave forms to ventricular pressures (30), stroke volume, cardiac output, rate of ventricular ejection, aortic flow, and other similar measures should be evaluated as well as the relation of these items to physical, clinical, and laboratory determinations so that interrelationships may be determined. This would be expected to increase the value of the BCG in the clinical and experimental situation. Until such studies are complete, it seems that the knowledge that multiple factors appear to alter the BCG wave form in varying degrees suggests caution in the quantitative use of the BCG standards derived from groups in determining such things as stroke volume, among others. The results of this study seemed to indicate that use of serial BCG's will be necessary for determining individual cardiovascular status. It is hoped that consideration of these numerous relationships will lead to a more meaningful BCG interpretation and consequently to its greater use.

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Table AI

Intercorrelations of Ballistocardiographic Waves, Durations and Amplitudes

	GF	GH	GI	GJ	GK	GL	GM	HI	HJ	HK	IJ	DQG	DQH	DQI	DQJ	DQK	DQL	DPQ	DGH	DHI	DHJ	DHL	DIJ	DJK	DRR
GF	-000	847	-056	715	040	778	-259	610	146	671	512	-088	137	143	159	141	120	-118	-002	-020	058	067	094	027	-220
GH	847	000	048	745	087	705	-243	791	024	816	581	-056	057	098	133	154	142	-071	-027	027	093	118	096	067	-123
GI	056	-048	000	-362	329	132	422	-649	-489	-228	-713	-129	194	219	221	143	112	-047	-009	-023	077	038	118	-027	-334
GJ	715	745	362	000	151	504	037	788	685	658	911	-112	-008	-023	001	-107	-091	-147	-146	-008	007	-089	017	-133	-035
GK	-040	-087	329	-151	000	-144	120	-268	-133	-647	-259	-137	040	-008	-173	-242	-287	-095	-135	-057	-209	-297	-215	-141	-193
GL	778	705	-132	504	144	000	-389	455	-013	622	320	-081	201	234	289	308	397	-043	056	-010	143	318	194	115	-122
GM	259	243	422	-037	120	389	000	-074	-320	116	-215	-028	176	194	289	338	333	005	099	-020	162	266	227	152	-197
DQH	137	057	-194	-008	-040	201	-176	-076	-075	020	-092	-604	000	418	377	190	158	-402	030	-670	-364	-217	167	-109	-223
DQI	143	098	-219	-023	008	234	-194	-060	-142	079	-114	-276	418	000	646	444	435	020	-015	393	335	274	064	-041	017
DQJ	159	133	-221	001	173	289	-289	-034	-144	202	-097	-156	377	646	000	603	532	095	102	147	724	385	802	-169	039
DGH	-002	-027	009	-146	135	056	-099	-014	-189	058	-105	778	030	-015	102	061	166	130	000	-043	079	153	144	-019	071
DJK	027	067	027	-133	141	115	-152	068	-271	133	-088	057	-109	-041	-169	684	571	039	-019	081	-085	606	-190	000	094
DHL	067	118	-038	-089	297	318	-266	065	-261	263	-084	260	-217	274	385	776	929	277	153	447	552	000	289	606	277
DPQ	-118	-071	047	-147	095	-043	-005	-025	-143	000	-089	356	-402	020	095	104	127	000	130	419	394	277	115	039	281
HI	610	791	649	788	268	455	074	000	317	761	879	038	-076	-060	-034	029	039	-025	-014	034	023	066	000	068	111
HK	671	816	228	658	647	622	-116	761	095	000	595	037	020	079	202	258	275	000	058	053	192	263	198	133	018
HJ	146	024	489	685	133	-013	320	317	000	095	731	-108	-075	-142	-144	-328	-289	-143	-189	-042	-091	-261	-078	-271	081
IJ	512	581	713	911	259	320	215	879	731	595	000	-026	-092	-114	-097	-144	-118	-089	-105	004	-029	-084	-039	-088	121
DQK	141	154	-143	-107	242	308	-338	029	-328	258	-144	-068	190	444	603	000	857	104	061	175	468	776	440	684	105
DIJ	094	096	-118	017	215	194	-227	000	-078	198	-039	011	167	064	802	440	355	115	144	-115	685	289	000	-190	041
DHJ	058	093	-077	007	209	143	-162	023	-091	192	-029	292	-364	335	724	468	420	394	079	644	000	552	685	-085	208
DQG	-088	-056	129	-112	137	-081	028	038	-108	037	-026	000	-604	-276	-156	-068	035	356	778	385	292	260	011	057	202
DHI	-020	027	023	-008	057	-010	020	034	-042	053	004	385	-670	393	147	175	199	419	-043	000	644	447	-115	081	242
DQL	120	142	-112	-091	287	397	-333	039	-289	275	-118	035	158	435	532	857	000	127	166	199	420	929	355	571	193
DRR	-220	-123	334	-035	193	-122	197	111	081	018	121	202	-223	017	039	105	193	281	071	242	208	277	041	094	000

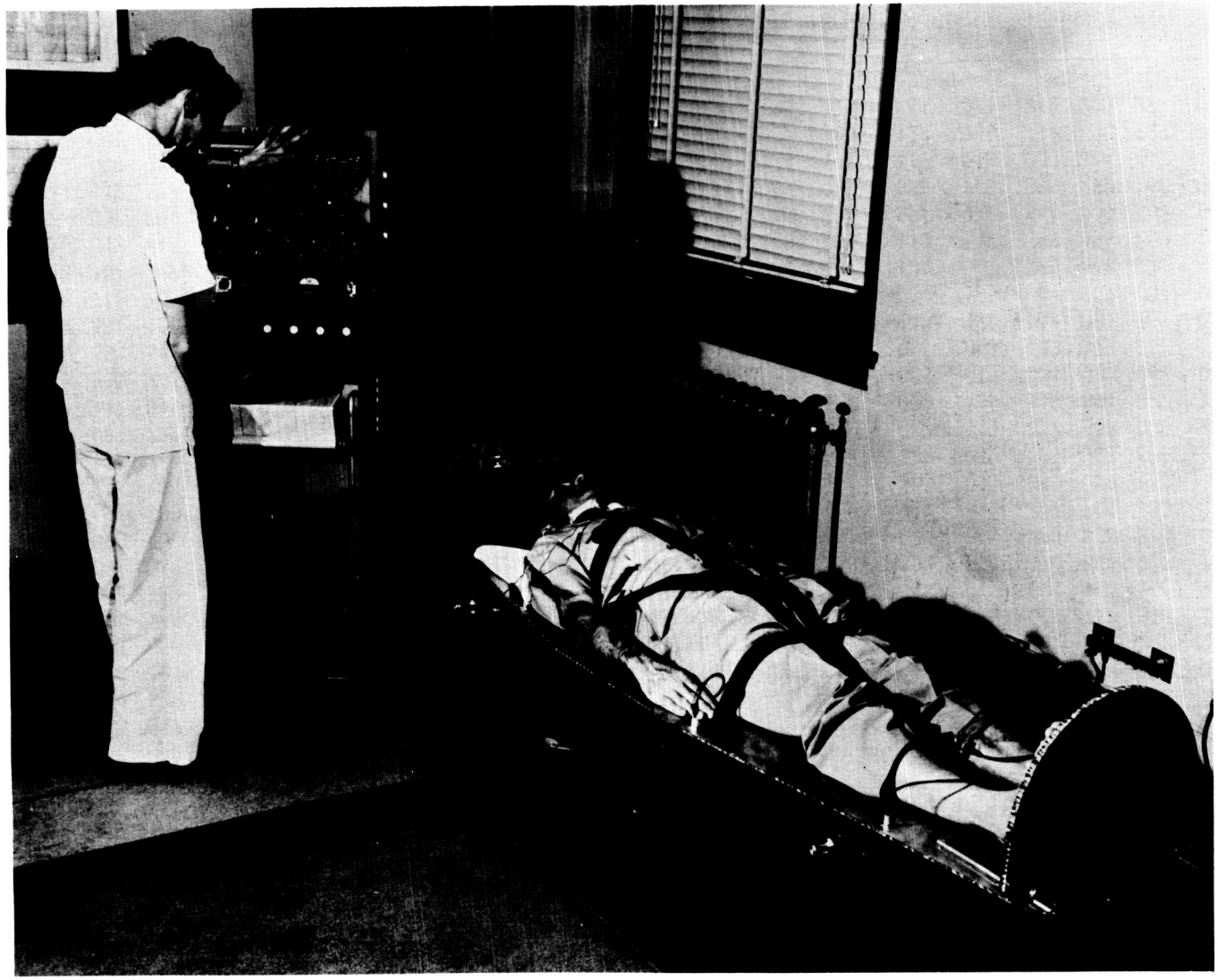

Figure A1

Astro Space Air Suspension Ballistocardiograph

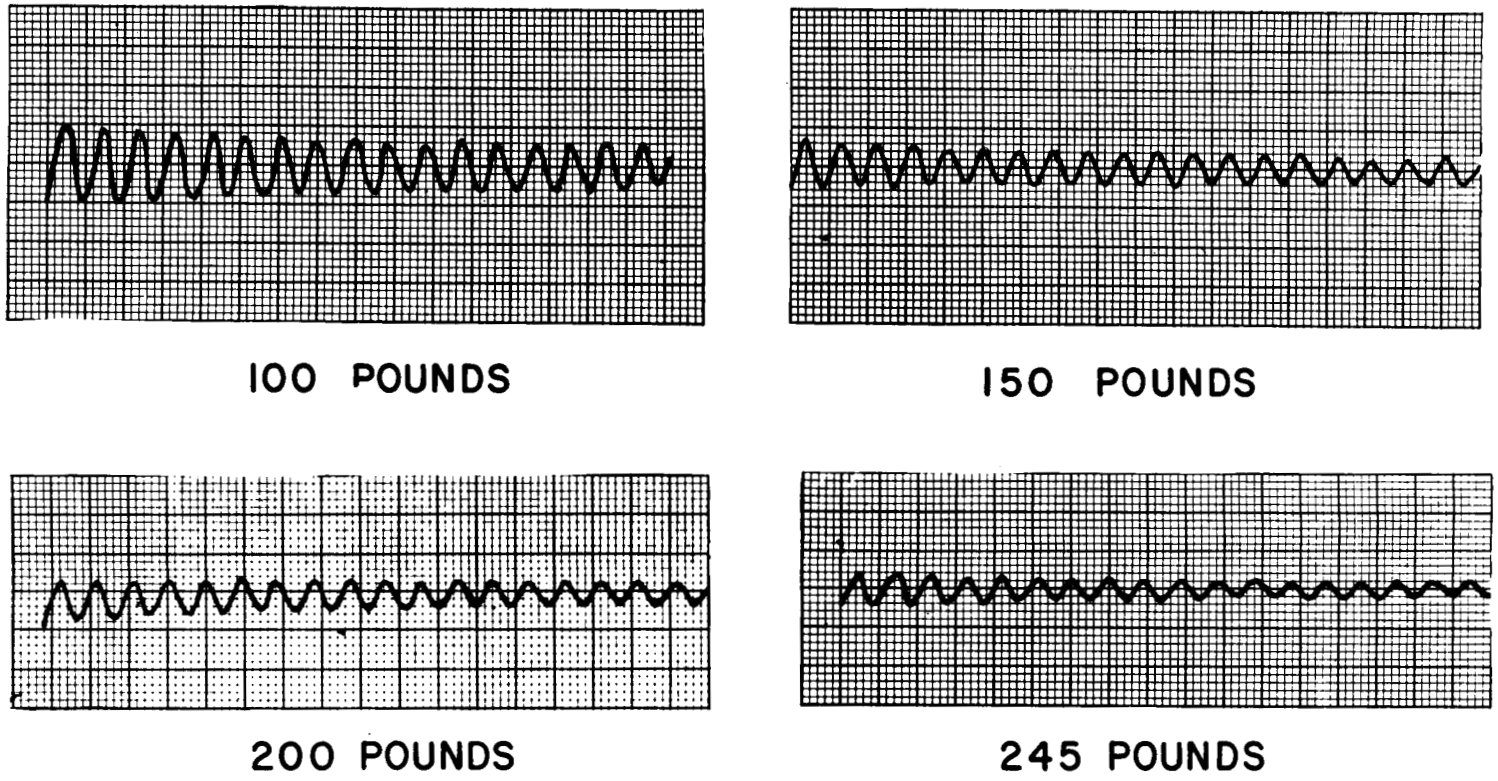

Figure A2

This figure illustrates the effect of weight addition to the air bed (100-245 pounds) during standardization procedure at the same attenuation (X 5).

APPENDIX B

MULTIPLE REGRESSION ANALYSIS FOR PREDICTION OF BALLISTOCARDIOGRAPHIC VARIANCE

MULTIPLE REGRESSION ANALYSIS FOR PREDICTION OF BALLISTOCARDIOGRAPHIC VARIANCE

TABLE B-1

CRITERION GI

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
AVERAGE DRR	0.334	0.363
WEIGHT LBS	0.370	-0.411
GLUCOSE 2 HR PP	0.393	-0.179
BODY FAT	0.426	0.450
ENDOMORPHY	0.475	-0.309
AGE	0.496	-0.140
MAX ST AFT EX	0.508	0.099
CHEST BREADTH	0.516	0.147
PULSE PRESS SUP	0.523	0.086

TABLE B-2

CRITERION GK

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
AVERAGE DRR	0.193	0.165
ECTOMORPHY	0.240	-0.349
ENDOMORPHY	0.282	-0.303
VITAL CAPACITY	0.312	0.141
SYST BP SUP BAS	0.340	0.129
MESOMORPHY	0.354	-0.202
CHEST A-P DIAM	0.371	0.177
CHEST BREADTH	0.381	0.166
WEIGHT LBS	0.389	-0.171

TABLE B-3

CRITERION HI

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
CHOLESTEROL	0.118	-0.129
AVERAGE DRR	0.160	0.153
CAL TRIGLY	0.188	0.128
CIG YEARS	0.211	0.186
CIG AMT	0.251	-0.107
WEIGHT LBS	0.267	-0.394
BODY FAT	0.318	0.440
ENDOMORPHY	0.347	-0.183
VITAL CAPACITY	0.365	0.102
GLUCOSE 2 HR PP	0.376	-0.108
PULSE PRESS SUP	0.382	0.076
CHEST BREADTH	0.389	0.104

TABLE B-4

CRITERION HJ

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
WEIGHT LBS	0.205	-0.207
CHOLESTEROL	0.257	-0.077
CHEST A-P DIAM	0.288	0.223
PULSE PRESS SUP	0.313	0.107
GLUCOSE 2 HR PP	0.333	-0.129
AVERAGE DRR	0.351	0.118
ENDOMORPHY	0.361	-0.432
BODY FAT	0.378	0.185
MESOMORPHY	0.390	-0.279
ECTOMORPHY	0.399	-0.180
MAX ST AFT EX	0.407	0.103
TRANS DIAM HT	0.415	-0.102
CIG YEARS	0.423	-0.083

MULTIPLE REGRESSION ANALYSIS FOR PREDICTION OF BALLISTOCARDIOGRAPHIC VARIANCE

TABLE B-5

CRITERION IJ

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
CHOLESTEROL	0.153	-0.138
WEIGHT LBS	0.219	-0.464
BODY FAT	0.261	0.424
ENDOMORPHY	0.310	-0.283
AVERAGE DRR	0.346	0.144
GLUCOSE 2 HR PP	0.369	-0.137
PULSE PRESS SUP	0.381	0.120
CAL TRIGLY	0.393	0.087
VITAL CAPACITY	0.405	0.144
BIACROMIAL DIAM	0.411	-0.135
CHEST BREADTH	0.421	0.153
MAX ST AFT EX	0.427	0.086
CHEST A-P DIAM	0.433	0.104

TABLE B-6

CRITERION DQG

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
HEIGHT STANDING	0.256	0.046
AVERAGE DRR	0.325	0.230
CAL TRIGLY	0.378	0.184
PBI	0.392	0.111
ECTOMORPHY	0.404	-0.286
WEIGHT LBS	0.413	-0.274
EXPIR RESERVE	0.424	-0.105

TABLE B-7

CRITERION DQH

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
HEIGHT STANDING	0.247	0.212
AVERAGE DRR	0.332	-0.261
EXPIR RESERVE	0.364	0.116
GLUCOSE 2HR PP	0.376	-0.098
PBI	0.386	-0.090
AGE	0.395	0.088
PULSE PRESS SUP	0.403	0.183
SYST BP SUP BAS	0.415	-0.142

TABLE B-8

CRITERION DQI

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
LEAN BODY MASS	0.336	0.313
AGE	0.378	0.183
SYST BP SUP BAS	0.406	-0.122
CHOLESTEROL	0.413	0.126
CAL TRIGLY	0.422	-0.106
CHEST A-P DIAM	0.430	0.100
CARDIOTHOR INDX	0.437	-0.092
PBI	0.443	-0.070

TABLE B-9

CRITERION DQJ

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
LEAN BODY MASS	0.310	0.296
AGE	0.345	0.154
CHEST A-P DIAM	0.368	0.151
CHEST BREADTH	0.397	-0.209
MAX ST AFT EX	0.412	-0.120
VITAL CAPACITY	0.423	0.635
INSPIR CAPACITY	0.432	-0.447
EXPIR RESERVE	0.443	-0.332
BODY FAT	0.449	0.109

TABLE B-10

CRITERION DQK

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
HEIGHT STANDING	0.389	0.324
VITAL CAPACITY	0.413	0.233
CARDIOTHOR INDX	0.432	0.129
AGE	0.444	0.101
CHEST BREADTH	0.451	0.142
BIACROMIAL DIAM	0.460	-0.124
PII	0.466	0.073

TABLE B-11

CRITERION DQL+DHL

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
HEIGHT STANDING	0.283	0.269
AVERAGE DRR	0.344	0.178
AGE	0.371	0.126
PBI	0.393	0.129
BODY FAT	0.408	0.131
GLUCOSE 2 HR PP	0.421	-0.101
CAL TRIGLY	0.430	0.084
VITAL CAPACITY	0.437	0.173
CARDIOTHOR INDX	0.445	0.109
BIACROMIAL DIAM	0.452	-0.103

TABLE B-12

CRITERION DPQ

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
AVERAGE DRR	0.281	0.325
WEIGHT LBS	0.341	0.237
MAX ST AFT EX	0.362	-0.125
CIG YEARS	0.382	0.139
CHEST A-P DIAM	0.399	-0.195
INSPIR CAPACITY	0.410	0.111
GLUCOSE 2 HR PP	0.417	0.070
PULSE PRESS SUP	0.425	-0.241
SYST BP SUP BAS	0.451	0.220

MULTIPLE REGRESSION ANALYSIS FOR PREDICTION OF BALLISTOCARDIOGRAPHIC VARIANCE

TABLE B-13

CRITERION DHI

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
AVERAGE DRR	0.242	0.231
CHEST BREADTH	0.321	0.183
PULSE PRESS SUP	0.354	-0.134
ECTOMORPHY	0.388	-0.141
GLUCOSE 2 HR PP	0.388	0.094
AGE	0.399	0.091
TRANS DIAM HT	0.406	-0.101
CHOLESTEROL	0.412	0.072

TABLE B-14

CRITERION DHJ

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
CHEST A-P DIAM	0.223	0.104
AVERAGE DRR	0.295	0.211
MAX ST AFT EX	0.331	-0.140
PBI	0.352	0.118
BODY FAT	0.369	0.151
AGE	0.378	0.093
VITAL CAPACITY	0.389	0.094

TABLE B-15

CRITERION DHL

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
AVERAGE DRR	0.277	0.302
HEIGHT STANDING	0.335	0.164
PBI	0.373	0.160
BODY FAT	0.397	0.119
AGE	0.408	0.094
CAL TRIGLY	0.419	0.116
INSPIR CAPACITY	0.428	0.088
GLUCOSE 2 HR PP	0.435	-0.080

TABLE B-16

CRITERION DJK

PREDICTOR	CUMULATIVE MULTIPLE R	Z SCORE WEIGHTS
HEIGHT STANDING	0.266	0.486
CHEST A-P DIAM	0.289	-0.130
CHEST BREADTH	0.320	0.358
LEAN BODY MASS	0.346	-0.116
CIG YEARS	0.369	-0.110
CAL TRIGLY	0.380	0.106
GLUCOSE 2 HR PP	0.393	-0.101
AVERAGE DRR	0.400	0.082
WEIGHT LBS	0.407	-0.289
EXPIR RESERVE	0.417	-0.164
BIACROMIAL DIAM	0.424	-0.156
SYST BP SUP BAS	0.430	0.071
VITAL CAPACITY	0.437	0.164
CARDIOTHOR INDX	0.444	0.092

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13. ABSTRACT

The availability of a large number of variables derived from clinical and laboratory evaluations of 200 middle aged males made it possible to relate them statistically to the BCG waves. Numerous significant correlations were found and these are discussed. It appears that, until the factors and their interrelationships are more precisely evaluated, the strictly quantitative use of BCG standards derived from groups to determine such things as stroke volume, among others, must be regarded with caution. The results seem to indicate that serial BCG's will be necessary for complete evaluation of an individual's cardiovascular status.

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